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# Cognitive Task Analysis of Decision Strategies of Submarine Sonar and Target Motion Analysis (TMA) Operators: Phase 1

Final Technical Report

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## Abstract

This work was carried out for The US Office of Naval Research under NICOP grant N00014-99-1-1044. This final report summarises the work completed in the first phase of a three year study to identify the factors that determine the effectiveness of sonar and target motion analysis operators in United States Navy (USN) and UK Royal Navy (RN) submarines. The aim of the programme is to highlight best practice in operator performance in a way that will contribute to training effectiveness. This report describes the progress made by the UK in preparing for this study and in implementing it. A parallel study of USN operators is being conducted by personnel from the Naval Undersea Warfare Center (NUWC), Newport. A comparative Cognitive Task Analysis will be a principal feature of the study.

As planned, the first phase of the UK work programme consisted mainly of programme set-up and of developing data-collection and analysis procedures that will facilitate effective comparison of UK and US findings. It also includes familiarisation with the technical-domain and initial data-collection.

An extensive programme of visits and data-collection sessions has been agreed. Common approaches to data collection and analysis have been agreed and are being developed. Data are being exchanged. US researchers have been able to visit RN establishments and to participate in some of the interviews. Analysis of technical and training materials has begun. Factors critical to success are being elicited. Detailed data collection from the Royal Naval Submarine School and from the School of Maritime Operations has begun. Cognitive task analysis has begun with both experts and novices. Some early results are described. The programme of future work is also described.

Keywords:
Sonar analysis, target motion analysis, cognitive task analysis, submarine operators, operator performance

## Executive Summary

### E1 Aims

E1.1 This report is the second deliverable due under NICOP agreement N00014-99-1-1044 of the US Naval International Co-operative Opportunities in Science and Technology Programme (NICOP). The customer for this work is the US Office of Naval Research. This report summarises UK progress in the first stage of a joint US/UK programme to compare UK and US sonar and Target Motion Analysis operators. It is believed that there may be systematic performance differences between the operators in these two nations: the programme will investigate those differences and suggest ways of maximising performance.

### E2 Programme Design and Set Up

E2.1 An important part of this stage of work was to develop a co-ordinated programme design that would provide the research resources and the access to Royal Naval (RN) facilities that are required to meet the objectives of ONR and the NUWC. Essential administrative issues such as authorisation, progress-review, reporting, security and intellectual property rights have been addressed. The agreed working procedures are described and the range of DERA, MoD and RN facilities that can be expected for the execution of this programme are identified. Arrangements for liaison and co-ordination with NUWC and ONR are described. The important process of developing and harmonising the experimental methods to be used by NUWC and DERA has been addressed. These are described and will be continually reviewed and updated.

### E3 Methods for Analysing Operator Performance

E3.1 The study will include several levels of analysis, including organisational issues (from tactics to career patterns), technical issues (e.g. levels of automation and interface design), physiological measures (heart rate and eye-movement) and performance measures (process and outcome). A comparative Cognitive Task Analysis (CTA) will be a principal feature of the study. Applied Cognitive Task Analysis (ACTA) is being used as a common tool in both the US & UK studies. Later work will include observations of experts operating in teams, performance measurement and physiological measurement.

### E4 Analysing Operator Behaviour

E4.1 Background information describing the training and development of operator skills and experience is being collected and training materials are being examined in detail. The way that operator functions are allocated within the command team is being explored: operating procedures and team processes are being analysed. Using ACTA, interviews are being conducted with individual trainees and experts to identify the cognitive skills and the cues and strategies that are used in sonar and TMA tasks. Later work will focus on common tasks and scenarios and will address performance measures and physiological measures.

### E5 Factors Critical to Performance

E5.1 Work has begun on identifying the factors that are critical to performance. The experience of the operators and the team processes that are used to exploit this are believed to be important factors. Ways of analysing team processes and of measuring performance are therefore being developed.

### E6 The Next Stages

E6.1 A common situational interview will be developed to standardise the focus of UK and US CTAs and to facilitate comparisons. The allocation of functions within the command team will be further clarified. CTAs will continue and will be used to identify each individual's contribution within the team. Objective measures of performance and physiological measures will be derived. Plans for the public dissemination of the initial results of the study are identified.

### E7 Conclusions and Recommendations

E7.1 Programme set-up has been completed. Collection of background data has begun and the cognitive task analysis of experts and novices has begun. It is concluded that team processes may be a significant performance factor. Methods to analyse these are being developed and it is recommended that full use should be made of the extended UK facilities on offer in the next phase of this programme.

**List of Contents**

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# 1 Introduction

## 1.1 Milestone Statement

1.1.1 This work was carried out for The US Office of Naval Research under grant N00014-99-1-1044 of the Naval International Co-operative Opportunities in Science and Technology Programme (NICOP). This is the first phase of a three phase, three year study to identify the factors that determine the effectiveness of sonar and target motion analysis operators in United States Navy (USN) and UK Royal Navy (RN) submarines. The Terms of Reference of this study are given at Appendix A. The aim of the programme is to highlight best practice in operator performance in a way that will contribute to training effectiveness. The report describes the progress made by the UK in preparing and conducting a cognitive task analysis of sonar operators.

## 1.2 Background

1.2.1 Opportunities are rare for conducting a detailed cognitive task analysis of submarine operator performance. Most endeavours in this area are driven by the design of new systems or by training needs analysis. This may be the first time that an international comparison of expert performance has been conducted with a view to capturing best practice and to optimising performance. There are many distinct differences between the two services that can affect the performance of USN and RN submarine operators (these include the submarines, the sensor and analysis systems, the personnel and the operating procedures). Experimental approaches that are sensitive to the similarities and difference have to be developed.

## 1.3 Aims

1.3.1 The aim of the programme is to compare UK and US sonar and Target Motion Analyst (TMA) operators. It is believed that there may be systematic performance differences between the operators in these two nations: the programme will investigate those differences and suggest ways of maximising performance. The programme is divided into three stages:

a) 'living' cognitive task analysis of UK Royal Navy sonar operators whilst they perform target detection and classification tasks;

b) report on initial observations and development of an experimental protocol;

c) data-analysis and report on the experimental results, with recommendations for training and system displays.

1.3.2 The aim of this stage is to begin the cognitive task analysis of novice and expert operators in both nations using co-ordinated data-collection procedures. Specific objectives are to:

a) establish options for data collection;

b) agree the data collection programme and develop a co-ordinated procedure for the cognitive task analysis;

c) begin the task analysis - examining the decision-making of both novice and expert, sonar and TMA operators in the RN as they conduct identification and classification tasks.

1.3.3 An interim report [1] described initial progress with the programme design and set-up. The aim of this report is to summarise the progress to date and the progress with the task analysis, in particular. Specific objectives for this report are to:

a) describe the planned programme of data-collection and analysis;

b) describe the agreed procedure for the cognitive task analysis;

c) describe the early results of examining the decision-making of novice and expert, sonar and TMA operators;

d) identify any issues for programme development and adjustment;

e) outline the next steps.

1.3.4 Later stages of the programme will include presentations to NUWC and ONR on the results of the work and the PIs will produce a joint report. Wider publication - in other defence fora and in non-defence media - will also be pursued.

## 1.4 Approach

1.4.1 In order to provide a full picture and to be able to accommodate the differences between individuals, systems and nations, the study will analyse operator performance from several different perspectives:

a) an Organizational analysis
The study will examine background factors in the two services, to identify the critical factors that determine performance and to agree ways of describing or measuring them;

b) an Observational analysis
The study will include examination and observation of both expert and novice Sonar and TMA operators during target detection and decision making. Operators will be observed at individual tasks and in team settings;

c) Decision analysis
Comparative Cognitive Task Analysis (CTA) is a principal feature of the study. Applied Cognitive Task Analysis (ACTA) will be used by both nations to capture the cognitive aspects of task performance. This will be augmented by other techniques. For example, Job Process Charts may be used to highlight the contribution of man and automation and of different team members to the tactical decision;

e) Experimental Analysis
Expert and novice operators will be observed and interviewed and their performance will be measured. It is also hoped to measure *perceptual processing* during decision making in a controlled task and to measure heart-rate during target detection;

f) Military analysis
The final part of the study will identify ways to translate the research findings into recommendations for best practice for training and skill-development.

## 1.5 Methodology

1.5.1 Co-ordination between the US and UK studies is an essential feature of the programme and this has been achieved in several ways. Early visits identified the areas for common and complementary endeavour. The NICOP research proposal was developed jointly {2}. Documents, such as the management plan for the UK study, were exchanged; and regular progress reports were provided. Study-results and draft reports have also been exchanged. Joint visits by the UK and US PIs to a number of MoD and RN sites have helped develop a shared frame of reference.

1.5.2 An important aim was to begin data-collection as soon as possible so that the constraints and the technical requirements (of the USN, RN, NUWC and DERA) would be identified early in the process and effective

procedures established.

1.5.3 The key aspects of the methodology include:

a) task
b) subjects
c) performance measures
d) CTA method
e) biodata.

1.5.4 Each of these aspects is considered in turn below.

**Task:** the tasks need to be carefully selected to fit in with ongoing training facilities and to accommodate differences between the following factors: UK & US. sonar and TMA, novice and expert. Task differences will be addressed by identifying the activities, operating conditions, performance standards and associated skills & knowledge that are required of operators in each rank and position. As this could be an important factor in the development of expertise and performance. national differences will be compared. For example, the two nations have very different policies on the balance between sea and shore training and this needs to be taken into account.

**Subjects:** a broad range of subjects will be made available. The RN will provide access to sonar and TMA experts and novices at all rates - as individuals and in teams. Permission has been given for the PIs (Dr Masakowski and Mr Hardinge) to observe expert sonar operators in action in command team trainers and at sea – if circumstances allow. It is recommended that full use should be made of the extended UK facilities on offer as part of this programme.

**Performance measures:** a range of objective and subjective performance measures will be used. These could include measures of task outcome. records of system interaction. team interactions. Instructor assessments and trainee ratings. It is hoped also to use physiological measures. Masakowski has measured the heart–rate of sonar operators during testing sessions {3}. If appropriate. such measures might be used in this study.

**CTA method:** This is a key part of the research programme and the method needs to be standardised. Chipman {4} highlights the important features of the methodology that should be identified. These include:

a) selection of tasks that merit detailed attention:

b) study of written materials and training materials to obtain a familiarity with the job and specialised vocabulary (this is especially important for a cross-cultural study of this sort):

c) selection of an unstructured. inclusive approach in the early stages to capture the factors that are important to the operators (this is especially relevant for a study like this. which has adaptive training, based on an expert-system. as the long term product):

d) selection of structured technique (e.g. goal/method graphs) to identify the rules and their organisation:

e) abstract nature of the knowledge involved (i.e. type of knowledge representation):

f) basis for selection of the CTA method (rationale or principles behind the method):

g) differences between understanding and approaches of experts and novices:

h) information about mental models of the task and the team context of the work:

i) information about the expert's mental organisation of the structures and functions of the equipment.

1.5.5 These requirements are being met in the following ways:

a) target identification and classification (for sonar) and target identification and location of targets (for TMA) are the selected skills for analysis. It is hoped to generate common target data so that the researchers can identify and compare the responses of the different national groups;

b) familiarisation with the jobs and their specialised vocabulary was deemed especially important for a cross-cultural study of this kind. Training syllabuses will be exchanged; doctrine and standard operating procedures (SOPs) will be compared; both the UK and US PIs observed and interviewed UK operators;

c) the analysis of critical factors affecting performance is being used to understand, to contextualize and to prioritise efforts. The UK as well as the US researchers used the Applied Cognitive Task Analysis (ACTA), (Militello et al, 1999 {5}). This method is flexible and inclusive and is well suited to accommodate the kinds of contextual factors that are important to these tasks and the differences that are a feature of this comparative study. It focuses on the decision-making processes and on the cognitive structures that individuals use. Ensuring that the principal investigators (PIs) conduct some analyses together in the UK will further develop standardisation between UK & US researchers' views and judgements. Approaches and interpretations will be discussed and harmonised;

d) the use of ACTA will be complemented by more structured techniques. Techniques such as COGNET {6} and MacSHAPA {7} are being considered. One graphical method being considered is Tainsh's Job Process Charts (JPCs). This provides a simple way of identifying the separate contributions of man and machine to the task processes (Tainsh 1982) {8}. As the US and UK use different systems and may have different degrees of dependency upon man and machine systems or upon individual and team processes to achieve similar tasks, this should be a useful way of highlighting important differences. This should provide a systematic way of representing technical knowledge and operators' knowledge structures. Cognitive Work Analysis (Vicente 1999 {9}) is also being considered. Cognitive Work Analysis (CWA) provides a broader view than CTA and may be useful for capturing the relationships that lie beyond the individual operator and for highlighting the different ways in which function is allocated within the Command team;

e) the abstract nature of the knowledge-domain is specifically addressed by the CTA methods being used (i.e. ACTA, JPCs, etc.);

f) differences between understanding and approaches of experts and novices will be addressed by examining operational procedures, the performance of trainees, Instructors and by observing expert operators conducting tactical scenarios;

g) approaches that systematically collect data on individuals' task goals and objectives will be considered as a way of measuring situational awareness and shared mental models (see Pearson 1999 {10});

h) examining the SOPs, using JPCs to highlight individual and team processes, and observing expert operators conducting tactical scenarios will provide information about the team context of the work These methods will also provide information about the expert's mental organisation of the structures and functions of the equipment.

**Biodata:** factors such as age, experience, educational background, IQ, sea experience, may be relevant. Tactical doctrine and SOPs may also present some important national differences. These will be considered and military experts used to assess or scale their relative importance.

### 1.6 Structure of the Report

1.6.1 The next section describes the progress made with setting up the programme. Then progress with the data collection and the results obtained so far are described in section 3. Section 4 identifies some of the background factors that might affect performance. Issues to be addressed in the later stages in the programme are described in section 5. The plans for the next stages of work are detailed in section 6. Conclusions and recommendations are given in section 7.

## 2 Programme Design and Set Up

2.1 Co-ordination between the US and UK studies was an essential feature of the programme and this was achieved in several ways. The NICOP grant was based on a joint proposal developed by the PIs (Dr Masakowski and Mr Hardinge). Two early visits by Dr Masakowski to the UK (in November 1998 and November 1999) made it possible to develop an effective joint research programme. The PIs visited all of the appropriate RN agencies to brief them on the goals and requirements of the project and to establish the basis for future interviews, data collection, etc. Details of the authorities and individuals consulted are given at Appendix B. Briefs on progress were provided to staff at the London office of ONR Europe {11}. Project planning documents (e.g. timetables, and protocols) were exchanged and basic data (e.g. CTA results) were exchanged. In these and subsequent visits, Dr Masakowski has been able to interview RN experts and examine system interfaces and training devices.

2.2 Activities in the early stages of the task consisted mainly of liaison with NUWC and staff-work with agencies in the UK and US. The main areas of development included:

a) the technical requirement:

b) contractual arrangements:

c) MoD approval for this form of international collaboration:

d) MoD approval for this line of technical research to proceed:

e) CINCFLEET's agreement to make specific RN facilities available.

2.3 DERA (CHS) has now obtained approval from MoD to proceed with this form of collaboration and from CINCFLEET for access to appropriate facilities. Because the training and experience of sonar and TMA operators in the submarine and surface fleets is very similar, the RN has provided access to both groups. Arrangements have been made to observe and interview trainees and instructors at the School of Maritime Operations (SMOPS), HMS DRYAD and at the Royal Naval Submarine School (RNSMS). Agreement has also been given for Dr Masakowski and Mr Hardinge to observe expert sonar operators in action in the command team trainer at HMS DRYAD and submarine teams in the command team trainer at Faslane or at Plymouth. Also, the RN has suggested that it should be possible for the PIs to observe teams at sea.

2.4 The technical programme has been developed and refined through liaison with Dr Masakowski. This established key details of the data collection programme. In broad terms, the number and range of interviews (i.e. sonar and TMA, surface and submarine, novice and experienced operators, trainees and instructors) were decided. The style and content of the interviews, the data to be collected, timetabling, etc were clarified. The available sources of data were reviewed and procedures for co-ordinated data collection were established.

2.5 Technical and experimental arrangements have been made in line with the agreement and as required to satisfy the requirements of the project. Programme set-up, therefore, has been completed.

## 3 Progress with Data Collection

### 3.1 Analysing Operator Performance

3.1.1 Background information describing the training and development of operator skills and experience is being collected. Factors such as training patterns, team structures and entry standards will be analysed and training materials are being examined in detail. The way that operator functions are allocated within the command team is being explored: operating procedures and team processes are being analysed. Using ACTA, interviews are being conducted with individual trainees and experts to identify the cognitive skills and the cues and strategies that are used in sonar and TMA tasks. Later work will focus on common tasks and scenarios and will address performance measures and physiological measures. In the UK, operators from both submarines and surface ships are being examined.

3.1.2 Cognitive Task Analysis (CTA) captures the cognitive aspects of task performance. ACTA was the method that was used. Lutzhoft & Susi 1999 {12} evaluated the ability of 'practitioners' rather than psychologists to use the ACTA tool to develop a cognitive demands table (CDT). They found that ACTA could be used successfully by SMEs - but that help was needed to develop the CDT. In our study, ACTA is being used by psychologists working with SMEs.

3.1.3 How a USN operator's task compares with that of his RN counterpart has to be established. The tasks, skills and knowledge that are appropriate to each level of operator in the RN will be identified and related to US practice.

### 3.2 Initial Results

3.2.1 The first interviews with individual operators have begun. Using ACTA, interviews with both expert and novice sonar and TMA operators are being conducted to identify the cognitive structures used during target detection and classification.

3.2.2 As the task is very complex and is executed as a team activity, the allocation of tasks within the submarine Command Team was studied. Appendix C describes the typical allocation of tasks between operators in a Trafalgar SSN. Comparable data from the USN should enable us to identify the critical aspects of team structure and role allocation that might be different in the US. The allocation of tasks within a surface towed array frigate was also considered (see Appendix D). This highlights some of the separate task elements that are combined within submarine operators' roles.

3.2.3 In line with ACTA procedures, Task Diagrams are being elicited from novice and expert operators. Appendix E gives an example of TD data being elicited for operators in a Trafalgar SSN. A TD is also being developed for operators in a Type 23 Towed-array Frigate (See Appendix F). The normal use of TDs is to identify the cognitive structures that are used in a job. With sonar and TMA operators, standard operating procedures (SOPs) provide a detailed formal definition of the minimum set of steps and functions that should be executed. These SOPs are normally available to all operators during the task (SOPs for TMA, for instance, are detailed in CB8713 (2D) {13}). In addition, numerous studies have identified some of the cues and responses that have been employed in past sonar and TMA operations (see, for example, {14}). In our study the TD will not only be used to identify which tasks the operators feel have high cognitive demands but also to identify areas where an individual's knowledge and use of procedures is different from SOPs. The results of our analysis of how operators approach the task and of the TDs that they generate will then be compared with the results of the US interviews from the parallel study.

3.2.4 Although the sonar function can be described in simple terms - such as Detect, Analyse and Classify - the operator's task is very complex. The operator, through training and experience, builds up a store of knowledge. This would include facts, beliefs and hypotheses that relate to the objects and events (e.g. equipment, command team, SOPs and target-data) that he has to deal with. The operator updates, maintains, and accesses his store of knowledge from information coming in to the command system through sensors, intelligence reports, reports from other members of the team, etc. He will diagnose the available information,

formulate objectives and alternative courses of action for achieving them, evaluate the alternatives, choose his action, monitor how that action is executed and evaluate the results.

3.2.5 Data for a Knowledge Audit is being developed (Appendix G gives a simple example of some of the data generated). Again, results from the US & UK studies will be compared. SOPs identify much of what operators *should* do. Part of our task will be to identify what operators actually do. Operators may do less than is recommended, they may execute tasks in a different sequence, and they may use additional cues and responses. They may follow SOPs exactly, but expert operators may weigh and judge items of information differently. A significant part of our study may not be eliciting cognitive strategies but identifying which cues and strategies are used by effective operators.

3.2.6 The scenario for a Simulation Interview is being developed. This will be defined in terms that are equally applicable to tasks that operators from US and UK submarines might execute. The scenario will be used to provide a common context for UK & US CTAs - so that the data from task diagrams, knowledge audits and cognitive demands tables are comparable. Some of the components of the approach used by Radtke & Frey {15} to develop SIs might also be employed to give a suitably rich picture. Klein's format for the CDT will be amended, as he recommends, in order to meet the specific requirements of this study. The changes are to serve two main aims: better to reflect the specific content of this study; and to provide a common format for data collection and reporting that will facilitate comparisons between the results of the parallel studies. So far the CTA has concentrated on identifying the content of the operators' tasks. In the next stage CTA will be used to determine interaction effects between display and operator performance

## 4 Factors Critical to Performance

4.1 Discussions with SMEs in the set-up phase of the programme revealed a number of factors that could affect UK operator performance. The visit reports {16 & 17} identify a number of these. Examination of previous research has also identified a number of factors. A study by Wylie, Mackie & Smith {18} examined the impact of different stressors on sonar performance. They surveyed the stresses arising from the task, the physical environment, supervision and personal health and they identified the extent to which each of 19 stressors affected different aspects of sonar performance. They distinguished between vigilance during search, visual information processing after contact, auditory information processing (after contact) reasoning/decision making during target classification and perceptual-motor processes during target tracking. Several of the factors that they considered (displays, workstation design, operator overload and Command pressure) could also be of relevance to our study.

4.2 The next stage of work will involve a systematic analysis of these factors to identify those that are critical to effective performance. It is important to determine the relative impact of these factors for the RN and USN and for the different sub groups (i.e. for sonar and TMA operators, for novices and experts). Therefore a way of describing or measuring these factors will need to be established. The factors so far identified are summarised at Appendix H. Initial data-collection has begun, but this should be prioritised and standardised.

4.3 Entry standards are one factor that might be important. The entry standard for RN sonar operators is defined in terms of the RN's Recruiting Test (RT) and of educational qualifications. RT correlates very strongly with traditional measures of IQ and the minimum standard corresponds to an IQ of 106-110. If the IQ equivalent of USN entry standards can be identified, it will be possible to determine whether entry standards could be a differentiating factor.

4.4 The way that individual operators' inputs are utilised by the command team may be an additional factor. Research by McDevitt {19} studied a number of submarine sonar teams and found a significant relationship between the use of cognitive procedural rules and performance. As teams became more expert, they used more rules. He found that a test of declarative knowledge (i.e. *knowing* the rules) did not predict team performance. However, after extensive practice (over a 14-day period) teams learned how to *use* more rules in their TMA and this enhanced performance. There was no significant difference in the performance scores in Sonobuoy Localization or in the rules-use in this type of scenario. A comparative evaluation of rule-use by UK and US TMA teams could provide a useful contribution to our study.

4.5 Training time is another factor that might be important. RN training patterns may differ slightly - depending upon the background and experience of the operator and the equipment fit of the platform to which he will be drafted. A representative Branch structure and training pattern for sonar operators is given at Appendix I. Detailed comparisons will be made between the training patterns, training times, input standards and training performance standards for the USN and RN.

4.6 Equipment fit and functionality are also likely to be a significant factor. The RN's main sonars are 2020 (hull mounted) and 2046 (towed array) for the submarine fleet. Sonar 2050 is the hull mounted system for the surface fleet. The user-friendliness of some of the interfaces may also be a significant factor. There are significant differences between different RN sonars: 2050 has a linear axis to represent the compass bearing. The lofargram for active sonar is represented as an upward waterfall. The way that the passive display is represented is not intuitive. It does not provide a traditional circular display (with ship's own position as the centre point and with a surrounding compass rose to help identify bearings) and it does not display the lofargram in the traditional form of downward waterfall. RN systems, however, have a Plan Position Interface (PPI) which provides a full screen display that operators can adjust. It is understood that this is not adjustable in corresponding US systems. Differences between the USN and RN systems, and their likely impact on operator performance, will be examined in some detail.

## 5. Issues

5.1 In the course of this first phase of the study, a number of issues were identified. These indicate some of the likely (additional) lines of development in the next phase of work that were not specifically identified in the original proposal. These include:

a) broadening scope of the study to identify and scale the impact of organisational factors in the RN & USN on the performance of operators;

b) pursuing other sources of performance data (e.g. the RN's passive area capability training (PACT) scores, performance scores from team training, performance measures from exercises such as Fleet Battle Hotel);

c) developing ACTA (especially the format of the cognitive demands table) to meet specific requirements of this joint study;

d) measuring *perceptual processing* during decision making in a controlled task and measuring heart-rate during target detection;

e) pursuing the development of common target/task stimuli to use with US & UK operators in our study;

f) utilising additional CTA methods to capture some of the complexities;

g) observing UK command team trials;

h) developing tools to identify the cognitive processes that should perhaps be used and to monitor and highlight those that are used and to relate these differences to operator performance.

## 6 The Next Stages

6.1 The work should enable the USN and RN to identify reasons for differences in operational effectiveness. It will focus on the human aspects of the task - that is, what operators do, how they do it, how well they do it. How the sonar operators' individual inputs are integrated into the command team's tactical decisions will also be considered. The technical systems (i.e. hardware and software) will be examined to be able to put these human performance aspects into context, but this is not the main focus of the programme.

6.2 The work so far has simply laid the foundations. It has set-up the machinery for a truly collaborative study. It has established a common basis for data collection and analysis - using techniques that can maximize the comparability of results. Initial data-collection has begun. The US and UK PIs have been able to conduct interviews together - and this will be of significant factor benefit in helping them integrate their parallel studies.

6.3 Opportunities to examine operator performance in such detail and to be able to conduct this kind of international comparison are rare. The work aims to translate research findings into recommendations for best practice for skill-development. It will identify aspects of best practice and will provide recommendations for the development of training methodologies and display designs. The pay off is to reduce training time, reduce decision-making time and to enhance operator performance for both groups.

6.3 NICOP sponsorship of the UK part of this programme has provided several specific benefits. It has generated data from RN establishments. It has enabled the researchers to develop a co-ordinated experimental programme and protocol that will provide data from both navies that will be comparable. UK involvement during this phase of the work has also contributed to the study methodology. Reviewing the experience of RN specialists has also encouraged the study to consider a broader range of critical factors.

6.4 The thrust of the work in this first phase has been on identifying what it is that RN operators do. This work will continue in the next phase - but that phase will also focus on identifying what it is that the RN operators do *well*. Collecting measures of performance will therefore be an important part of that phase of work. The opportunity to observe RN teams working in the command team trainers and at sea will be of significant benefit.

6.5 The third phase of the programme will concentrate on identifying the performance differences between USN and RN operators and on determining what we could do about that. The work here would include the following steps:

- compare the procedures, the systems used and the processes of skill development
- relate performance levels achieved to the critical differentiating factors identified
- analyse the data to determine the effects of training, displays and decision support on proficiency
- utilise the data to predict operator proficiency
- identify best-practice

6.6 To carry the work forward a number of objectives have yet to be realised. As identified in the original proposal, the next phase of work is to include the following activities:

a) the PIs will each provide a letter report giving a detailed description of the data collected from phase 1 - to be incorporated in a joint report;

b) they will identify and agree a list of the factors that appear to be significant determinants of performance for either or both groups;

c) from this they will develop a co-ordinated method for recording the factors and of measuring their importance and measuring associated outcomes where possible;

e) provide a systematic analysis of expert and novice perceptual and cognitive strategies during a target detection task.

6.7 In line with the requirements of a NICOP grant, the results of the study will be publicly disseminated. This work will be presented at the 5th Naturalistic Decision-Making Conference in May 2000. It will also be presented at defence forums. A presentation will be given to the next meeting of the US/UK International exchange agreement (IEA5928) in the summer of 2000 and to the appropriate Panels in The Technical Co-operation Programme (i.e. Technical Panels 2 & 9 (Training Technology & Human Factors in Warships)).

## 7 Conclusions and Recommendations

7.1 The objectives of the first phase of the programme have been completed. Programme set-up has been completed and co-ordinated and experimental procedures have been established. Background data are being collected, and the cognitive task analysis of expert and novice sonar and TMA operators has begun.

7.2 It is concluded that, as well as individual differences in operator capability, factors such as team processes may be a significant performance factor. Methods to analysis these are being developed and it is recommended that, as well as examining the operators' inputs, the study should address the way that individual operator inputs are processed by the command team.

7.3 It is anticipated that this study will enable indicators of best practice to be provided. The analysis of the data on the issues outlined above, will provide guidelines on aspects as diverse as: sonar operator entry selection levels; individual operator performance levels; training content and delivery; human computer interface design; and integration of the sonar/TMA process to command team decision making. It is therefore recommended that the next phase of the programme should be supported.

7.4 The response from the RN has been very positive. Discussions identified common interest in other areas relevant to operator performance such as task automation, improving human factors integration, Netcentric warfare and collecting exercise data. It is recommended that full use should be made of the extended UK facilities on offer as part of this programme.

7.5 In addition to the required deliverables, it is recommended that, in Phase 2 of the programme, presentations on this work should be made at the next Meeting of Information Exchange Agreement 5928 and to TTCP Panel 2 (Training Technology) and Panel 9 (Human Factors in Warships).

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## 9. Glossary of Terms

| | |
|---|---|
| ACTA | Applied Cognitive Task Analysis |
| ADAC | Acoustic Defence Analysis Centre |
| AI | Action Information |
| ASWSC | Anti Submarine Warfare Sensor Co-ordinator |
| Bio | Biological data |
| CATMA | Computer Aided Target Motion Analysis |
| CDT | Cognitive Demands Table |
| CHS | Centre for Human Sciences |
| CINCFLEET | Commander in Chief Fleet |
| CO/XO | Commanding Officer/Executive officer |
| CPO | Chief Petty Officer |
| CSR | Crank shaft rate |
| CTA | Cognitive task analysis |
| DEMON | Demodulation |
| DERA | Defence Evaluation and Research Agency |
| DRIC | Defence Research Information Centre |
| EFR | Engine firing rate |
| FOSM | Flag Officer Submarines |
| FOST | Flag Officer Sea Training |
| HCI | Human Computer Interface |
| HMS | Her Majesty's Ship |
| JPC | Job process chart |
| KA | Knowledge Audit |
| LOM | Leading operator mechanic |
| Met | Meteorological information |
| MoD | Ministry of Defence |
| NICOP | Naval international co-operative opportunities in science and technology programme |
| NUWC | Naval Undersea Warfare Center |
| OJT | On Job Training |
| OM(AW) | Operator Maintainer (Above water) |
| ONR | Office of Naval Research |
| PI | Principal investigator |
| PO | Petty Officer |
| PO(R) | Petty Officer (Radar) |
| PSC | Passive Sonar controller |
| PSD | Passive Sonar Director |
| PSO | Passive Sonar Operator |
| PWO | Principal Warfare Officer |
| RN | Royal Navy |
| RNSMS | Royal Naval Submarine School |
| SCOOW | Ship Control Officer of the Watch |
| SI | Simulation Interview |
| SME | Subject Matter Expert |
| SMOPS | School of Maritime Operations |
| SOPs | Standard operating procedures |
| SR | Sound Room |
| SVP | Sound velocity profile |
| TS | Tactical system |
| TMA | Target Motion Analysis |
| TTCP | The Technical Co-operation Programme |
| UK | United Kingdom |

## Appendixes

### Appendix A: Terms of reference of the study

### Cognitive Task Analysis of Decision Strategies NICOP N9-04: Task Breakdown

The research programme will be conducted in three phases as described below.

**Phase I**
Mr. Hardinge will conduct a living cognitive task analysis of UK Royal Navy sonar operators whilst they perform target detection and classification tasks.

This phase will comprise the following activities:

a) Establish options for data collection (i.e. subjects, locations, tasks, etc)
b) Agree a co-ordinated procedure for cognitive task analysis
c) Examine the decision-making of novice and expert operators conducting identification and classification tasks at HMS DRYAD
d) Examine the decision-making of novice and expert operators conducting identification and classification tasks at HM Naval Base Faslane

Deliverable: Agreed data collection programme and procedure: letter report summarising the process and outcome of Task Analyses.

**Phase II**
Mr Hardinge (and Dr. Masakowski) will report on their initial observations and develop an experimental protocol.

This phase will include the following activities:

a) Mr Hardinge and Dr. Masakowski will each prepare a report of their observations, to be incorporated in a joint report
b) They will identify and agree a list of the factors that appear to be significant determinants of performance for either or both groups. (These factors might include operator characteristics, task features, work processes, HCI features and an understanding of system functionality.)
c) From this they will develop a co-ordinated method for recording these factors, of measuring their importance and of measuring associated outcomes where possible.

Deliverable: Letter report giving a detailed description of the data collected from phase 1- formatted as a chapter for a combined report.

**Phase III**
Mr Hardinge (and Dr. Masakowski) will analyze and report on their experimental results. Recommendations for training and display will be developed.

This phase will include the following activities:

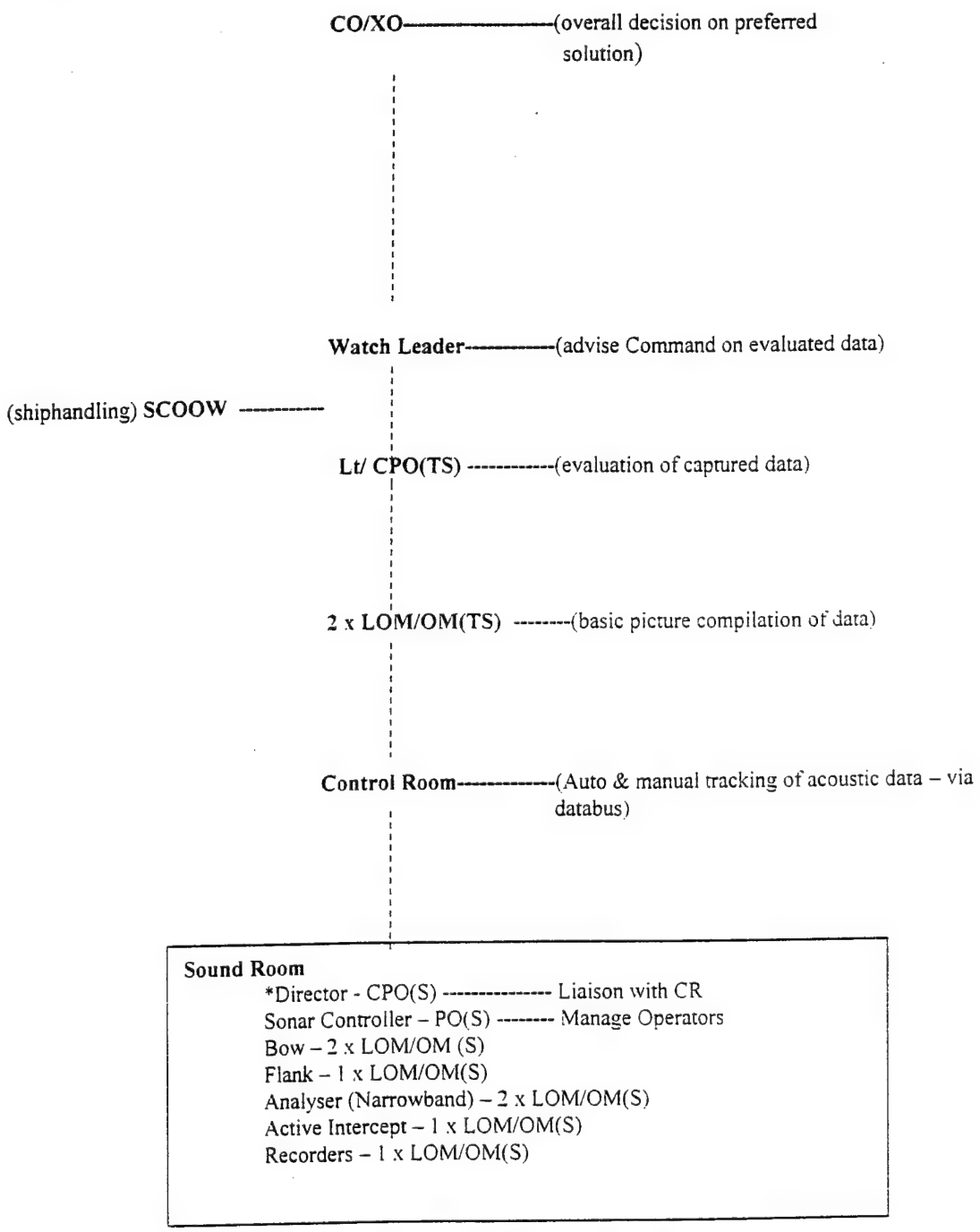
a) Mr Hardinge and Dr. Masakowski will co-ordinate the methods of analysis and will report on the experimental findings
b) Lessons learned, best practice, recommendations for training and recommendations for sonar display will be developed
c) Mr Hardinge and Dr. Masakowski will exchange the results with the NUWC study-team (subject to each participant's national security requirements).

Deliverable: (Joint) presentation of results to NUWC. Inputs to joint final report that will include recommendations for training and recommendations for sonar displays

**Appendix B - Individuals and Establishments Consulted**

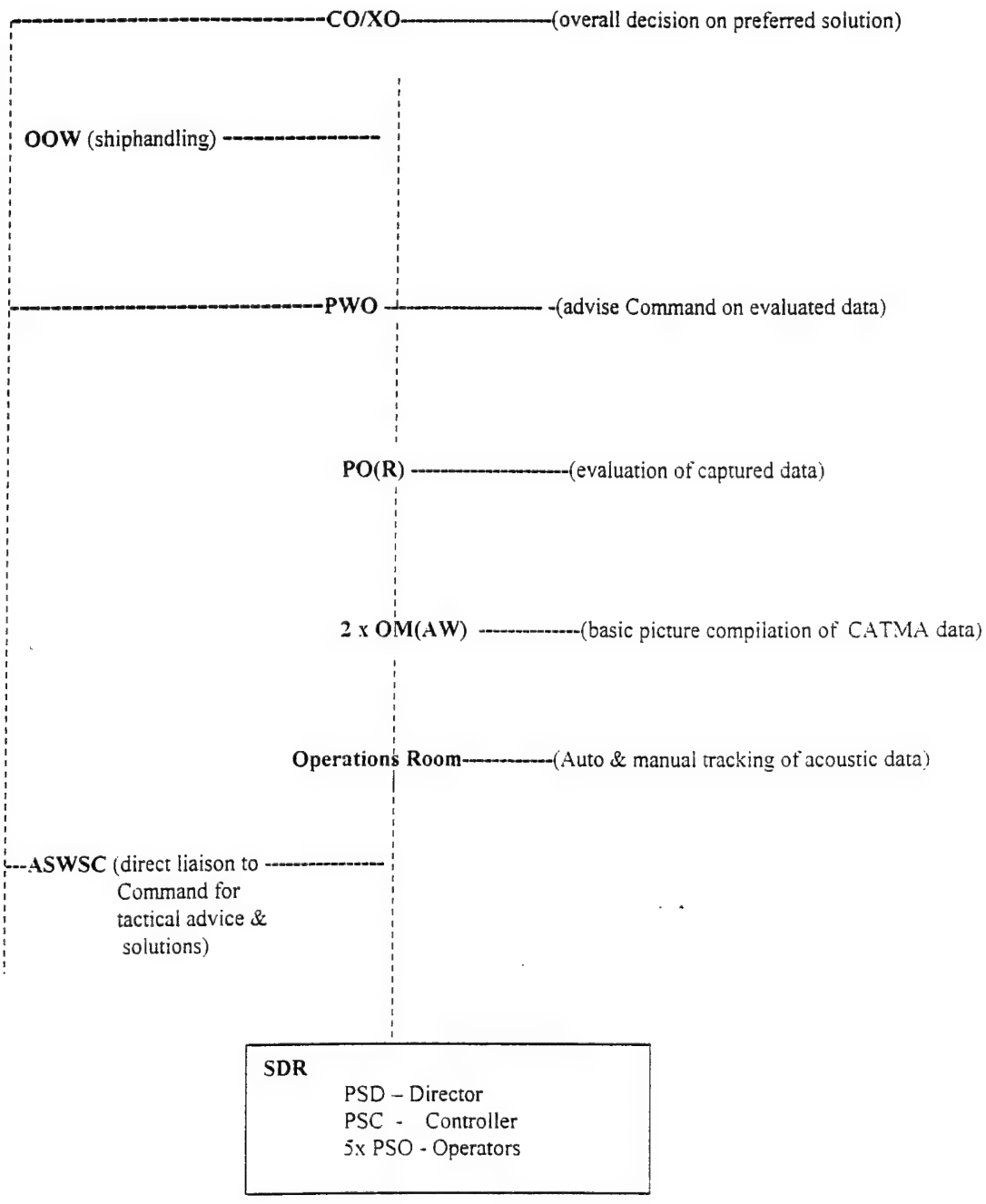
| | | | |
|---|---|---|---|
| WO Carver | Military Adviser | DERA Sea Systems, Winfrith. | SSN team structure and task allocation |
| Mr J Channell | Training Manager | SMOPS, HMS DRYAD, Portsmouth | Sonar & TMA training. CTA subject |
| Cdr C Christie | SFTO | FOSM, Northwood | |
| Cdr Dalton | MoD(N) R (Strat) | MoD, MB, London | Common aspects of surface & submarine sonar & TMA performance |
| Mr Dunn | CBT Manager | SMOPS, HMS DRYAD, Portsmouth | Content of passive sonar training |
| Cdr D Forbes | OC, ADAC | DERA, Farnborough | Differences between UK & US operating |
| CPO Gowman | Instructor | SMOPS, HMS DRYAD, Portsmouth | Sonar &TMA training, CTA subject |
| Lt Cdr Hayward | DSWTO | RNSMS, Portsmouth | UK training pattern: differences between UK & US training and operating |
| Cdre F Hiscock | ACOS(W) | Fleet Warfighting & Training Brd, CINCFLEET | Programme set-up |
| Mr T Mansell | Researcher | DSTO | Issues & focus in Aus R&D programme on submarine sonar & TMA |
| Lt Cdr K Mardon | SOASW, SMOPS | HMS DRYAD, Portsmouth | UK training pattern |
| Mr Mike McDevitt | Researcher | KAPOS Assocs, Inc, USA | USN TRACE programme |
| Cdr J Pett | SO1, N7 Training | FOSM, Northwood | Programme set-up |
| Mrs E Porteous | Researcher | DERA, HMNB Portsmouth | Entry standards |
| Cdr F Price | DOR(Sea) R | MoD, MB, London | US UK Liaison |
| Cdr S Robinson | SO1 UWW | N7, CINCFLEET, Northwood | Programme set-up, RN liaison |
| Mr G Schwartz | Researcher | DSTO | Focus of Aus R&D programme on submarine TMA; CWA. |
| Dr M Tainsh | Researcher | DERA (CHS), Farnborough | HF aspects of MoD submarine sonar R&D |
| Dr G Walker-Smith | R(C)2 | MoD/IRC, London | UK US R&D liaison |
| Prof W Weldon | ONR | ONR, London | Programme set-up |
| Mr G Vongas | EC(AWB)Sc2.8 | MoD, MB, London | US UK Liaison |
| WO White | ASW1 | SMOPS, HMS DRYAD | Sonar & TMA training |
| Mr L Yeo | R(CS)1 | MoD/IRC, London | MoD contracts |

**Appendix C: Allocation of sonar activities in a Command Team (Trafalgar Class SSN)**

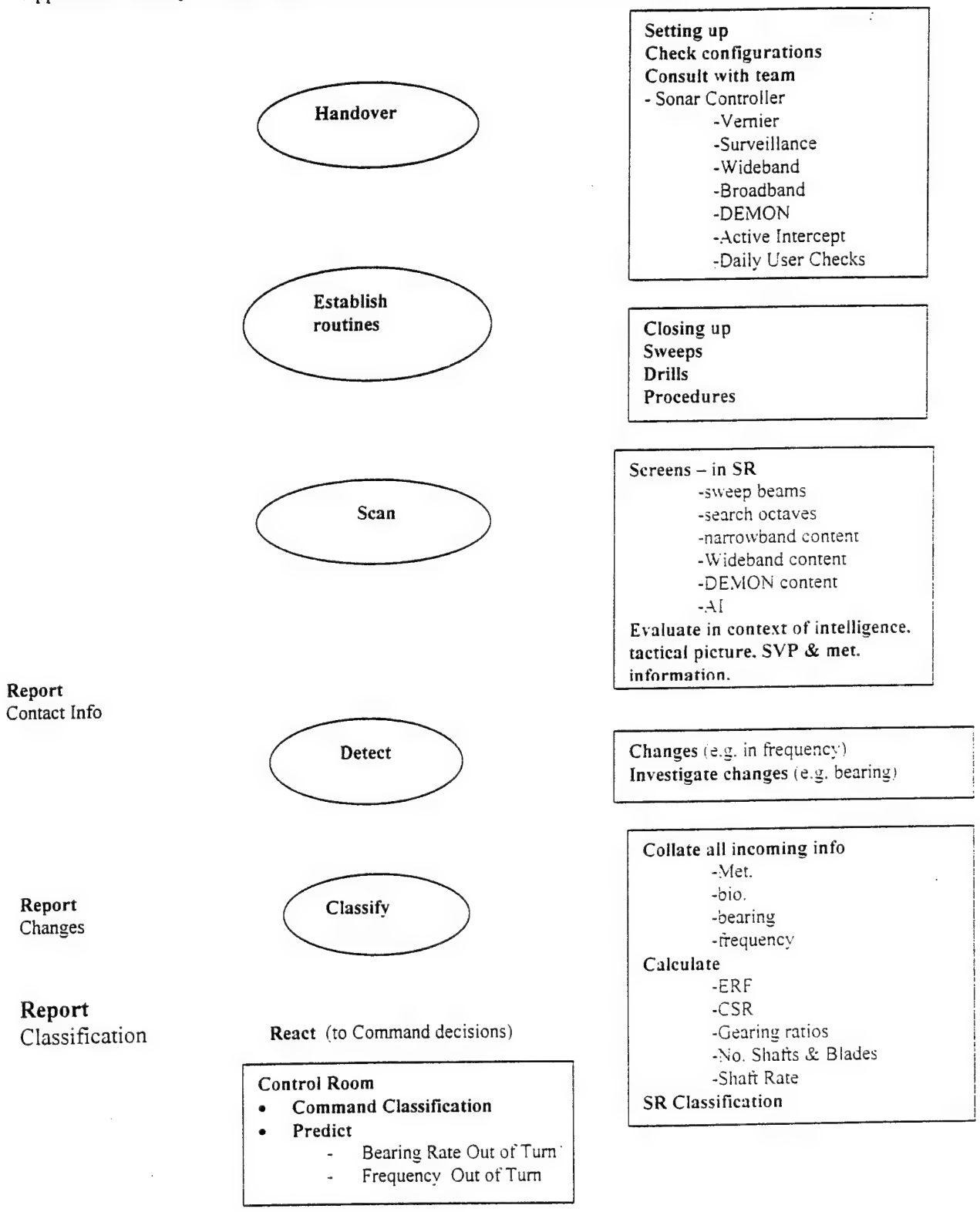



*CPO(S) (colloquially CHOPS) is the overall director for the compilation of the sonar picture. He is free to move to the Control Room to speak directly with the Sonar Officer, the Watch Leader or the Command as necessary.

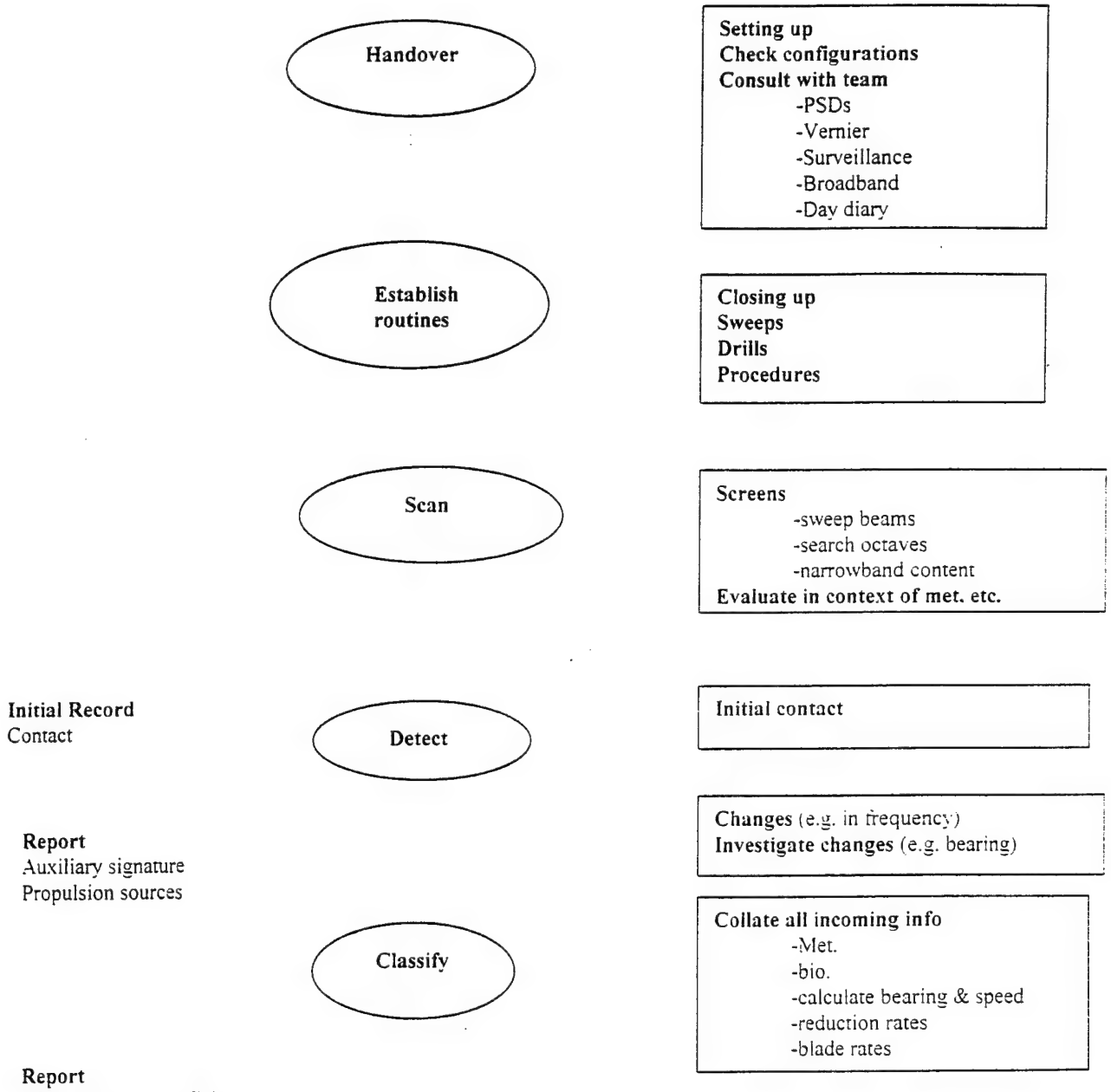
**Appendix D: Allocation of sonar activities in a Command Team (Type 23 Frigate)**



**Appendix E: Example Task Diagram data for Passive Sonar Operations (Trafalgar Class SSN)**



**Appendix F: Example Task Diagram data for Passive Sonar Operations (Type 23 Frigate)**



**Appendix G: Example items from Knowledge Audit for Passive Sonar Controllers**

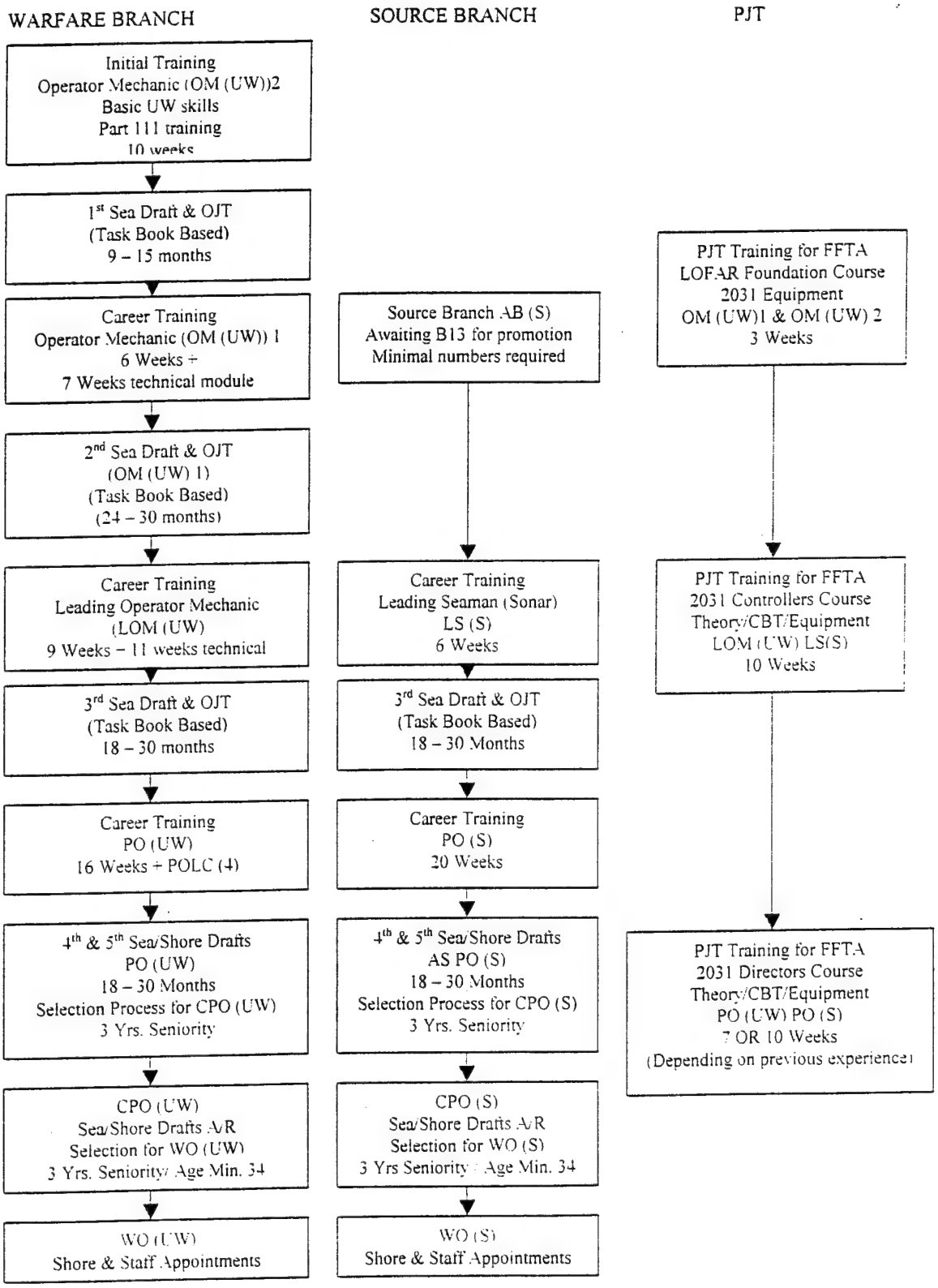
| Task | Cues & Strategies | Why difficult |
|---|---|---|
| | - Follow set drills<br><br>- Select correct frequency ranges when configuring sonar | |
| Detect target:<br>Make target contact | - Look for new lines at known threat frequencies<br>- Identify changes in harmonic structure<br>- Identify changes within frequency spectrum | - Lack of opportunities to gain experience<br>- High density merchant shipping area<br>- Bad weather: high sea-state<br>- Problems with equipment<br>- Poor intelligence<br>- Poor management<br>- Poor morale within sonar team |
| Predicting sonar range | - Predicted sonar ranges<br>- Expected threat directions<br>- Topography<br>- bottom bounce<br>- upswelling of sound<br>- Temperature/Pressure/Depth profile<br>- Direction of sea<br>- Water conditions<br>- Depth of towed array<br>- Convergence zones<br>- Cavitation inspection speed<br>- Array flow noise limitations<br>- Array length<br>- Array safety depth<br>- Track history | - Area of search<br>-Time allocated for search<br>- Mean line of advance<br>- Other shipping<br>- Land masses<br>- Ambient noise<br>- Alertness of operators<br>- Good beams<br>- Own ship radiated noise |

**Appendix H: Determinants of operator performance**

1. The following list of factors was identified during the first stage of the programme. They are offered for consideration during the next stage of work. A systematic review of the factors involved and a process for identifying the most important, from both UK and US perspectives, will be conducted at that stage.

| Serial | Factor | Measure | Importance | Comment |
|---|---|---|---|---|
| 1 | Doctrine: OPS | | | |
| 2 | Team structure | - # and structure | | |
| 3 | Allocation of tasks | - CWA and/or JPC; study | | |
| | | | | |
| 4 | Operator characteristics: | | | |
| 5 | Entry standards | IQ | | |
| 6 | Age | - Mean age at each sonar position & each rate | | |
| 7 | Rate or rank | - Link this to specific tasks | | |
| 8 | Time in service | - Mean No. of years | | |
| 9 | Time at sea | - # of tours & Mean No. of months | | |
| 10 | Exercise experience | - # of ASW exercises & recency | | |
| | | | | |
| 11 | Equipment: | - type of sonar | | |
| 12 | displays | - ergonomic checklist, user reports | | |
| 13 | functionality | - SME assessment | | May be classified |
| 14 | reliability | - " " | | " " " |
| 15 | Range & accuracy | - " " | | " " " |
| 16 | DSS | - " " | | " " " |
| | | | | |
| 17 | Task features: shifts | - examine rosters | | |
| 18 | Work processes | - examine SOPs, observe teams | | |
| | | | | |
| 19 | Training: Training time | - examine timetables | | |
| 20 | Training performance | - examine Training Objectives; analyse training progress tests | | |
| | | | | |

**Appendix I: Branch and Training Structure of Sonar and TMA Operators (Surface Flotilla)**



**Appendix J: Summary of work programme for phases 2 & 3 of the work programme**

**Cognitive Task Analysis of Decision Strategies - Phase 2:**
**What do RN Operators do, and how well?**

| OBJECTIVES | APPROACH |
|---|---|
| • Complete cognitive task analyses during target detection task RN novices & experts, surface and submarine, sonar and TMA tasks<br>• Measure the effect of different factors on performance<br>• Determine the relative impact on performance of the key factors | • Living task analysis to describe operator activity<br>• Record operator's target detection and classification performance<br>• Utilise data to understand operator proficiency<br>• Use cognitive task analysis to determine interaction effects between display and operator performance<br>• Code & analyse data to determine effects of training & displays on performance proficiency |
| **MILESTONES & DELIVERABLES** | **PAYOFF** |
| • Experimental protocol to quantify performance differences in perceptual & cognitive strategies<br>• Complete and comparable data-set<br>• Report giving a detailed description of the results of the task analyses | • Focus research effort<br>• Collection of complementary data-set<br>• Ascertain the comparative importance of the critical factors |

**Appendix J: Summary of work programme for phases 2 & 3 of the work programme**

**Cognitive Task Analysis of Decision Strategies - Phase 3:**
**What are the performance differences between USN and RN operators? What should we do about it?**

<table>
<tr>
<td>

OBJECTIVES

- Co-ordinate methods of analysis
- Combine results
- Identify:
  - lessons learned
  - best practice
  - recommendations for training, display and decision support

</td>
<td>

APPROACH

- Compare procedures, systems used, processes of skill development
- Relate performance levels achieved to the different factors
- Analyse data to determine effects on proficiency of:
  - training
  - displays
  - decision support
- Utilise data to predict operator proficiency
- Identify best-practice

</td>
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MILESTONES & DELIVERABLES

- Contribution to a (joint) final report
- Joint presentation of results to NUWC
- Recommendations for training, display and decision support

</td>
<td>

PAYOFF

- Reduced training time
- Decrease in decision time
- Enhanced human performance

</td>
</tr>
</table>

## 11 Initial Distribution List

External:

| | |
|---|---|
| Dr M McCluskey | ONR |
| Lt Cdr D Schmorrow PhD | ONR |
| Dr Y Masakowski | NUWC |
| Dr G Matzke | ONR |

Internal:

| | |
|---|---|
| Dr K Chaplain | Business Area Manager, CHS 3 |
| Prof. E Farmer | Technical Manager, CHS |
| Cdr S Robertson | SO1 AWW N7 CINCFLEET |
| Dr G Walker-Smith | MoD/IRC |
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6. AUTHOR (S) **NEIL M HARDINGE**

| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**DEFENCE EVALUATION AND RESEARCH AGENCY, FARNBOROUGH, HAMPSHIRE, GU14 0LX, UK** | 8. PERFORMING ORGANIZATION REPORT NUMBER<br>**DERA/CHS/MID/CR000008/1.0** |
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11.SUPPLEMENTARY NOTES
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12a. DISTRIBUTION AVAILABILITY STATEMENT

12b.DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

**This report describes the first part of a three year study to identify the factors that determine the effectiveness of sonar and target motion analysis (TMA) operators in United States Navy (USN) and UK Royal Navy (RN) submarines. The aim of the programme is to highlight best practice in operator performance in a way that will contribute to training effectiveness. This report describes the progress made by the UK in preparing and conducting a cognitive task analysis of sonar operators.**

14. SUBJECT TERMS
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15. NUMBER OF PAGES
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